Chapter 3
METHODS FOR DEVELOPING MINIMUM FLOW CRITERIA

Minimum flow criteria developed for the Caloosahatchee River and Estuary were based on six sources of information: (1) development of the Valued Ecosystem approach for establishing the minimum flow, (2) a review of the literature, (3) development of flow/salinity relationships for the estuary, (4) review of the results from field, laboratory, and growth rate studies, (5) development of a *Vallisneria* growth model (6) application of the SFWMM model to produce flow scenarios for the Caloosahatchee River under various base case and future case conditions, and (7) review of the District's Estuarine research programs underway within the Caloosahatchee estuary.

VALUED ECOSYSTEM COMPONENT (VEC) APPROACH

The SFWMD's Caloosahatchee Estuary research program supports application of a resource-based management strategy similar to the Valued Ecosystem Component (VEC) approach developed by the U.S. Environmental Protection Agency as part of its National Estuary Program (USEPA 1987). There are several definitions of a Valued Ecosystem Component in the literature, For example:

1. *"A resource or environmental feature that is important (not only economically) to a local human population, or has national or international profile, or if altered from its existing status, will be important for the evaluation of environmental impacts of development and the focusing of administrative efforts"*
2. *"Any part of the environment that is considered important by the proponent, public, scientists and government involved in the assessment process. Importance may be determined on the basis of scientific concern or based on cultural values"*.

For the purposes of this study, the VEC approach was based on the concept that estuary management goals can best be achieved by providing suitable environmental conditions for selected key species or key groups of species that inhabit the estuary. In this case, the key species identified to be protected against significant harm is submerged aquatic vegetation, specifically *Vallisneria sp*. (commonly known as tape grass or wild celery) present within the upstream fresh/brackish water portion of the river. Submerged aquatic vegetation are important to the ecosystem in that they sustain an important water resource function by providing food, and habitat for forage fish, shellfish, and serve as nursery areas for many juveniles species of fish that are recreationally or commercially important (Day *et al*., 1989; Heck et al., 1995; Kemp et al., 1984; Lubbers et al. 1990; Orth et al. 1984). This approach assumes (a) that environmental conditions suitable for VEC will also be suitable for other desirable species; and, (b) that enhancement of VEC will lead to enhancement of other species. Through this strategy, management objectives will be attained by providing a minimum flow that will protect this community against significant harm.

The VEC approach was applied to the Caloosahatchee River and Estuary based on the following scientific assumptions: Seagrass (*Thalassia testudinum*, *Halodule wrightii*) meadows are prevalent at the seaward/outer end of the system where salinity can be significantly impacted by high volumes of freshwater discharged to the estuary from S-79 or from local basins. Therefore, these seagrass communities represent the VEC for assessing the impact of high flows within the estuary. At the other end of the spectrum, beds of *Vallisneria americana* (wild celery or tape grass) are prominent in the fresh-brackish water (low salinity) portion of the inner estuary. These communities are sensitive to increased salinity values that result from reduced volumes of water low discharged to the estuary during low rainfall periods. Since this report focuses on establishing a minimum flow that will the protect the ecosystem against significant harm, *Vallisneria* was selected as the VEC of choice in that it represents a number of the primary water resource functions that need protection during low flow periods.

LITERATURE REVIEW

- A literature review (Estevez, 2000) was conducted for the Caloosahatchee Estuary to review and evaluate the following: (a) existing information that may be available for determining a MFL for the estuary, (b) approaches that have been used by other water management districts or agencies to establish an MFL, and (c) the validity of using the VEC approach (as discussed above) to define a minimum inflow. The scope of work included the following: (1) identify individual species or biological communities that could be used as indicators, targets, or criteria for determining a minimum flow for a riverine estuary; 2) determine how these indicator species or indicator communities have been affected in estuaries that have long histories of structural and/or hydrologic alteration; 3) review lessons learned by other water management districts, other states, and other counties with respect to establishment of MFLs for estuaries; and 4) evaluate the District's VEC approach to establish a MFL for the Caloosahatchee River/Estuary.
- The libraries of the SFWMD, Mote Marine Laboratory and the author (Estevez, 2000) were reviewed for relevant citations. Electronic searches were performed using open-access, limited-access and subscription-access databases, including BIOSIS, First Search, Cambridge Scientific Abstracts, DIALOG, and federal agency sources. Key words were searched to cover rivers, estuaries, tidal rivers, instream flow, minimum flow, dams, barrages and related terms. Journals that would typically publish relevant papers were also reviewed.
- An additional literature review was also conducted to identify (a) the key species or groups of organisms that may benefit from utilizing Vallisneria grass bed communities within the Caloosahatchee estuary, (b) life histories of these species, and (c) tolerances of these species to low salinity levels. Key documents reviewed included Chamberlain and Doering 1998a, 998b; Patillo *et al*. 1994; Bartone and Smith 1998; Day *et al.* 1989; Harris *et al*. 1983; Hoffacker 1994; McNulty *et al.* 1972; Carter and Rybicki 1985; Gunter and Hall 1967; Heck *et al.* 1995; Jassby *et al*. 1995; Irlandi *et al.* 1995; Kemp *et al*. 1984; Killgore *et al.* 1989; Lubbers *et al*. 1990; Orth *et al.* 1984; Phillips and Springer 1960; Twilley *et al.* 1875; USFWS 1957; Wagner and Austin 1999; and Zieman and Zieman 1989.

DEVELOPMENT OF FLOW/SALINITY RELATIONSHIPS

A one dimensional hydrodynamic/salinity model (Bierman 1993) was completed for the Caloosahatchee River and estuary and was used in the previous efforts, however, this model does not provide a satisfactory relationship of salinity and flow from S-79 under low flow (0 to 500 cfs) conditions for the inner estuary. In response, District staff developed an empirical relationship between salinity at a given location within the estuary as a function of flow (memo from Ken Konyha, June 29, 2000, **Appendix A**). The model was developed using measured flow from S-79 and salinity at the Ft. Myers Marina (22 km upstream of Shell Point) for the period from January, 1992 to November, 1999. The relationship is an improvement over Bierman's earlier numerical 1-dimensional modeling of salinity which ignored contributions of flows from the tidal watershed and therefore overestimated salinity under low flow conditions. A comparison of Chamberlain's predicted salinity to Bierman's predicted salinity under uniform flow conditions is provided in a memo from Ken Konyha, June 29, 2000, **Appendix A**. Chamberlain's relationship of salinity to S-79 flow is as follows:

y=a(exp(-bx)+c(exp(-dz)), where

y = salinity (ppt)

x = 30-day back-averaged flow (cfs) at S-79 [During calibration it was found that the 30-day back-averaged flow provides the best overall estimate of salinity in the estuary. This simpler estimate of flow replaces the more complex rule proposed in the draft document of December 16, 1999.]

z = distance upstream of Shell Point (km)

a,b,c, and d are empirical coefficients with a = 19,b = 0.002, c = 150, and d = 0.25

The model was coded as an Excel spreadsheet and has an instruction worksheet, a flow worksheet (with data imported from an external source), a salinity worksheet, and a graphical display worksheet. The salinity worksheet, when exported as a comma-separated-variable file (*.csv) becomes an input file for the *Vallisneria* model. For this application salinity is determined at 1 km intervals along the length of the estuary beginning 12 km upstream of Shell Point and ending 32 km upstream of Shell Point (memo from Ken Konyha, June 29, 2000, **Appendix A**)

Field and Laboratory Studies

Vallisneria is a freshwater aquatic grass that is tolerant to low salinities and, therefore, is frequently found in the transitional zone from freshwater to oligohaline habitats. Since *Vallisneria* grass beds are sedentary and salinity varies in response to inflows, understanding its tolerance to salinity is important in predicting its distribution and density. A literature search was conducted on the biology and life history of *Vallisneria* to determine if its salinity tolerance information was adequate to avoid the need for additional field and laboratory efforts (Bortone *et. al*., 1998; Doering et al. 1999). While there have been several determinations of the salinity tolerance of *Vallisneria* (Bourn 1932, 1934; Haller et al. 1974, Twilley and Barko 1990) estimates did not agree and there was little information concerning factors that might modify salinity tolerance. However, qualitative data for the Caloosahatchee indicates that shoot (leaf) densities decline when salinity is above about 10 ppt (Chamberlain et al. 1996) and growth ceases at 15 ppt (Doering *et al.* 1999). Since limited detailed information was available on the effects of varying salinity and duration of exposure of salinity on *Vallisneria,* a field sampling program, was initiated to measure salinity and *Vallisneria* shoot density as well as other growth parameters at four locations along the salinity gradient. During the first year (1998) of field sampling (Bortone 1999), plants thrived since they were not exposed to high enough salinities to cause mortality. During 1999, however, dry season salinity data documented the effects of salt water, thus providing a data set for calibration of a *Vallisneria* growth and mortality model being developed with data from laboratory experiments. The District conducted laboratory experiments that simulated typical saltwater intrusions during the dry season (Doering *et al.* 2000).

Development of a *Vallisneria* Growth Model

In addition to above work, *Vallisneria* daily growth rate algorithms were developed relating changes in blade length, blade density and shoot density to salinity (Doering, memo dated March 22, 2000, Appendix A). Although algorithms were established for all growth parameters, this evaluation only used shoot density predictions since it is the most appropriate measure of abundance. The main purpose of the evaluation was to predict decreases in abundance (mortality) due to salinity and not to reproduce the annual cycle of *Vallisneria* abundance. Because the model was not intended to reproduce an annual cycle of abundance, shoot density was 'reset' each year to a specified value every October. In general then, a 31-year simulation of *Vallisneria* shoot density identifies those years in which dry season salinity would have caused decreases in abundance. Specifically, the model best represents effects of salinity on the abundance of *Vallisneria* during the early spring portion of the dry season when this VEC or resource function is most needed. The form of the Growth Rate algorithm is identical for each of the tape grass characteristics, only the coefficients change. The Growth Rate equation is:

$N_{(t+1)} = N_{(t)} \exp^{(r*((K-N(t))/K)))}$

Where

$N_{(t+1)}$ = quantity on current day
$N_{(t)}$ = quantity on previous day
K = scaling factor (maximum value)
rbar = growth coefficient function

The growth coefficient function, rbar, used in the above equation is the average of the daily growth coefficient function, r. r is defined as:

r = r1 – r2*y,
r1 = seasonal zero-order growth coefficient
r2 = seasonal first-order growth coefficient
y = daily salinity (mg/l).

Table 6. *Vallisneria* Growth Response Parameters

N	K	Wet Season Coefficients		Dry Season Coefficients	
		r1	r2	r1	r2
Blade Length (cm)	20	0.051	0.0039	0.017	0.0039
Blade Density (/m2)	8000	0.0673	0.00557	0.034	0.0052
Shoot Density (/m2)	110	0.084	0.0031	0.035	0.0052

Source: Doering, 2000

This algorithm has seasonably variable growth coefficients. Dry season coefficients apply from September 30 through April 14; wet season coefficients apply from April 15 through September 30. All parameters have been calibrated to measured data collected in the Caloosahatchee Estuary.

The model also simulates some seasonal effects. It simulates a sloughing of leaves at the start of the dry season by resetting blade length (to 25 cm), shoot density (to 80 shoot/m^2) and by reducing blade density (to 50% of the previous day's density). It simulates a recovery at the start of the wet season that sets the minimum blade density (to 350 blades/ m^2); if the blade density is increased, blade length is also reset (to 4 cm).The plant response model was written in Fortran. Details pertaining to development of the model are provided in **Appendix A** (memo from P. Doering, March 22, 2000)

Application of Flow/Salinity and Growth Rate Models into the SFWMM

Model Integration

The above two companion models developed by District staff to evaluate flow salinity relationships and simulate *Vallisneria* growth were incorporated into the South Florida Water Management District Model (SFWMM v. 3.7). The SFWMM is a regional-scale computer model (SFWMD, 1999) that simulates the hydrology and management of the water resources of South Florida ranging from Lake Okeechobee to Florida Bay and includes water deliveries and environmental targets (including meeting low flow criteria) for both the Caloosahatchee River/Estuary and the St. Lucie Estuary (SFWMD, 1999). The combination of these three models was used to simulate flow scenarios and *Vallisneria* growth response for the Caloosahatchee Estuary for a 31-year period of record.

Developing a 1995 Base Case and Future (2020) Case Flow Scenarios

The first flow scenario developed included the historic (1965-1995) rainfall record, 1995 land use and current SFWMD operations to produce a time series of flows through S-79 as a Base Case (1995). A second scenario was developed for the future (year 2020) incorporating future land use and components of the "Comprehensive Everglades Restoration Program (CERP)" designed to improve the operation of the Central and Southern Florida (C&SF) Project, restore the Everglades system, and provide for other water related needs of the region (USACE and SFWMD, 1999). The 2020 with CERP scenario produced flows from the Caloosahatchee watershed to the river and estuary and incorporating the low flow environmental needs of the estuary (Konyha memo; June 1999, October 1999,and January 2000, Appendix A). These estuarine environmental requirements were determined from previous District research and included the desired range of flows of 300 to 2,800 cfs with consideration of a natural variation within this range as well as values below and above this range. Details of this modeling effort and results are available in Appendix A (Konyha memo; June 1999, and June 2000.

SUMMARY OF ESTUARY RESEARCH

The SFWMD's effort in managing flows to the Caloosahatchee Estuary has focused on the development of ecological criteria. Oysters and submerged aquatic vegetation (SAV) have been selected as key indicators of a “healthy” estuarine system because they provide food and/or habitat for much of the estuarine community. Accordingly, the SFWMD is evaluating ways to establish healthy, self-perpetuating populations of these organisms in the Caloosahatchee Estuary. Hydrodynamic salinity models have been developed which can predict salinity regimes in estuaries based on freshwater inflows (Scarlatos 1988). Geographic Information System coverages (including substrate type, shoreline features, and current SAV and oyster distributions) are being developed for the estuary. Comparing these coverages with salinity model output will help refine where oysters and SAV could occur once flow management strategies are in place. Optimization models (Otero et al. 1995) are being used to help predict how much water must be held back in the watershed, as well as to determine schedules for releasing the stored water to meet the salinity requirements of oysters and SAV. Ultimately this information will be coupled with watershed models to evaluate specific "in watershed" management scenarios needed to meet the inflows necessary to maintain healthy SAV and oyster community requirements.

Research is being conducted by the Florida Center for Environmental Studies, in conjunction with the SFWMD, to investigate the *in situ* influence of freshwater inflow and salinity on tape grass (*Vallisneria sp.*) to determine if freshwater inflow requirements are needed to permit a "healthy", thriving ecosystem in the upper portions of the Caloosahatchee Estuary. This work will help the SFWMD in its charge to make informed management decisions regarding optimal flow volumes and discharge schedules to preserve, increase, or maintain existing submerged aquatic vegetation present in the upper portions of the Caloosahatchee Estuary as well as the communities of organisms associated with it.

Also, the SFWMD and the U.S. Army Corps of Engineers (USACE) are conducting a research study to characterize seasonal fluctuations of submerged aquatic vegetation (SAV) in the upper Caloosahatchee Estuary, lower Caloosahatchee Estuary, San Carlos Bay and Pine Island Sound. SAV will be mapped, on the basis of distribution and proximity to significant freshwater input, using Submersed Aquatic Vegetation Early Warning System, which was developed by scientists at the USACE-Waterways Experiment Station. This project will provide information on spatial and temporal variations in biotic communities needed to determine biotic status and trends. Furthermore, the project will provide information on the effect of management actions on ecosystems to researchers and managers assessing the success of future water management policies designed to protect and enhance SAV communities.

Additionally, researchers at the University of Florida Coastal and Oceanographic Engineering Department are developing a coupled circulation/water quality model for the Charlotte Harbor Estuarine system for the SFWMD. The model will be developed in three phases. Phase I includes a preliminary 3-D circulation model will be developed and calibrated with available hydrodynamic data and then applied to address the impact of the Caloosahatchee River Estuary on circulation in Pine Island Sound, with particular focus on the effect of the Sanibel Causeway. This is scheduled for completion December 1999. Phase II will review and analyze available water quality data and a 3-D water quality model will be developed. An assessment of the effects of the Sanibel Causeway on circulation and salinity will be accomplished. Phase III will calibrate the coupled hydrodynamics and water quality models and apply them to address the impact of loading from the Caloosahatchee watershed on the water quality in the Caloosahatchee Estuary,San Carlos Bay, and Pine Island Sound. Phase II is scheduled for completion in late 2000 and Phase III in 2001.

Previous SFWMD research provided the foundation for development of a MFL concept for the Caloosahatchee River and Estuary. Results of these research efforts produced two important findings:

1. A flow of about 300 cfs discharged from structure S-79 was needed to maintain a freshwater-brackish salinity regime that will support a healthy submerged aquatic vegetation community (Vallisneria sp.) within the inner estuary, and
2. A minimum flow less than 300 cfs if sustained for a period of time, would result in increased salinity levels that will cause mortality of *Vallisneria* communities in the region of its greatest coverage (Chamberlain et al. 1995; Chamberlain and Doering 1998a, 1998b). Therefore, river flows within the range of 300 cfs can be considered a threshold flow that needs to be maintained to avoid *Vallisneria* mortality. Results of these studies indicated the need for a more detailed understanding of the effects low flows and their duration on submerged aquatic vegetation in order to define significant harm for the estuary.

The procedures for establishing a more detailed understanding of the effects of low flows and its impact on submerged aquatic vegetation communities were to:

(1) Determine the relationship between low-level freshwater discharges from S-79 (0 to 500 cfs) and salinity in the inner estuary where *Vallisneria* is found in abundance

(2) Develop a more comprehensive understanding of the salinity tolerances of Vallisneria by conducting a thorough literature search. This done under a contract (Estevez, 2000)

(3) Implement a field monitoring program and conduct laboratory experiments designed to ascertain the response of *Vallisneria* to varying salinity levels and durations

(4) Conduct modeling scenarios using the South Florida Water Management Model (SFWMM) to analyze the levels of freshwater discharge from S-79 that would have occurred over the last 31 years using historical rainfall and today's land use to provide a base case scenario that examines the effect of these discharges on *Vallisneria* over the 31-year simulation.

(5) Identify engineering solutions to be implemented within in the watershed that would provide the appropriate freshwater discharges from S-79 for development of a MFL recovery and prevention strategy

(6) Develop a management strategy based on SFWMM output that predicts the response of Vallisneria to: (a) a 31-year base case of simulated flows; (b) a 31-year base case of simulated flows with additional flows added to avoid significant harm and; (c) 31-years of flows modeled for a recovery and prevention strategy.